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Industry Study

Final Report
Strategic Materials

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Strategic Materials (STRATMAT) 2017

ABSTRACT: *The United States has come to rely on a number of strategic materials to provide hi-tech consumer goods, advanced defense technologies, and renewable energy capabilities. Yet it remains dependent on imports for a good portion of these materials, either because they do not exist in the U.S. in mineable deposits, or their mining and processing is uneconomic. Current import levels satisfy U.S. demand for these materials, yet access to these imports is highly dependent on geopolitical factors. This survey investigates ways to mitigate the risk of supply disruption.*

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The STRATMAT team would like to extend a heartfelt thanks to all of the industry, government, academic and international leaders in this area who took time out of their busy schedules to educate, inform and promote creative thought within our team.

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Introduction

The Eisenhower School prepares its graduates to lead the strategic institutions and activities associated with the integrated development and resource execution of national security and national defense strategies.[1]

Purpose and Methodology

The Eisenhower School at the National Defense University focuses on the resource component of national security,[2] with seminars analyzing the relationship between industry and government from a strategic national security perspective.[3] The Strategic Materials Industry Study was formed to analyze strategic materials - the raw mineral resources required for all aspects of the economy and critical to national defense - and the long-term potential impacts of maintaining secure supplies on the U.S. defense industrial base and on the national economy.[4] The study focused on the U.S. strategic materials industry's ability to provide the means to support the National Security Strategy's ends and ways. The academic approach first focused on the science of minerals and the process of transforming these minerals into materials. It then moved to understanding the industry by examining players and drivers, and finally by investigating the political and economic factors affecting the industry.[5] The Strategic Materials Industry Study interacted with leaders from government, industry, and other stakeholders in the National Capital Region, OH, UT, and CO, and traveled to the Republic of Chile to gain an international perspective on the industry. This survey provides near-, medium-, and long-term recommendations for U.S. mineral security, outlining some areas where industry, academia, regulators, lawmakers and investors can collaborate to strengthen national security.

Summary of Findings

The United States relies on the free market to meet resource needs, and the defense industrial base is no exception to 21st century globalization trends. The strategic materials required to build the weapons systems and defense capabilities utilized by the U.S. military are resourced from across the globe. The free market has not failed to meet U.S. demand, but the U.S. has become over-reliant on potential adversaries for many strategic materials. A sudden change in supply or demand could result in market disruption and immediate shortages or exponential price increases. In response to this risk, the nation must resist the urge to walk away from global commodity trade and resource everything from within national borders; geology precludes this notion. All the elemental needs of the nation are not found in American soil. Additionally, economics plays a role. Wages and environmental controls mean that some nations can produce strategic materials at a significantly lower cost. The U.S. should take advantage of these lower costs, but be prepared for market disruption. The following recommendations to the U.S. government serve as a roadmap in order to hedge against market failure:

Proposed Legislative Changes:

S.145 and H.R. 520 (The National Strategic and Critical Minerals Act)

- Amend proposals to identify the Department of the Interior (DOI) as the permanent lead agency. (Near-term action) *We welcome the proposal for a government-wide definition of "strategic materials" to eliminate confusion over issues of governance, resource allocation, and foreign policy, and the proposal of a 30-month time limit provisions for permitting processes.*

H.R. 1407 (The METALS Act)

- Amend proposal to allow the use of the Strategic Material Investment Fund to cover exploration and R&D (research and development) for downstream activities related to the exploitation of strategic materials. (Near-term)

- Extend length of loans from the proposed Strategic Investment Fund up to fifteen years, determined by a tiered system based on need. (Near-term)

Education

- Continue strategic investment in the fields of science, technology, engineering and mathematics (STEM) education to sustain a well-educated and effectively trained workforce to support the U.S. mining industry. (Near-term)

- Create partnerships between the government, the U.S. mining industry, national trade associations, and academia to ensure that primary, secondary, and post-secondary education and vocational training programs align with domestic workforce demands. (Near- to medium-term)

Secondary Supply

- Conduct research and development on collection and recycling methodologies in order to produce an organic secondary supply of strategic materials. (Near-term)

- Incentivize organizations to cultivate a shift from a consumable society to a reusable society. (Medium-term)

Stockpile

- Determine the actual stockpile quantity of a strategic material based on the length of time required to bring online domestic production or a secondary supply. (Near- to medium-term)

- Classify the contents and quantities of the stockpile to prevent adversaries from exploiting the information on the list. (Near-term)

- Detach stockpile authority from the National Defense Authorization Act (NDAA) and delegate authority to buy and sell strategic materials to the Defense Logistics Agency (DLA). (Medium-term)

International Partnerships

- Continue to pursue bilateral and multilateral trade agreements with historically allied nations and emerging democracies remain an effective hedge against single points of trade failure and market disruption. (Near-, medium-, and long-term)

Technology and Automation

- Increase research and development funding in order to develop an economical method to process tailings; increase funding to develop technology and automation for deep sea and space mining so the U.S. can remain at the forefront of the technology. (Medium- to long-term)

Strategic Materials Industry Definition

Before addressing the issue of minerals security, it is imperative to first define our terms. There is no single, universally accepted definition of a strategic material, or criteria for determining those that are strategic, critical, or both. There is little agreement even within the U.S. government. The Department of Energy (DoE) characterizes as critical materials those minerals required for clean energy technologies that also face supply risks.[6] The Department of Defense (DoD) distinguishes between strategic and critical materials, categorizing as strategic those materials essential to important defense systems, unique in their functions, and for which there are no viable substitutes. It defines critical materials as strategic materials for which the DoD dominates the market, the DoD's full and active involvement and support are necessary to sustain and shape the strategic direction of the market, and there is significant and unacceptable risk of supply disruption due to vulnerable U.S. or qualified non-U.S. suppliers.[7]

For the purposes of this survey, the Strategic Materials Industry Study will utilize a broad definition in order to capture the overall supply challenges that the U.S. faces or could encounter with regard to certain minerals. Some of the same mineral materials required for defense applications contribute to national security in a broader sense, owing to their roles in providing energy security or economic prosperity. This study therefore defines **strategic materials as non-fuel minerals with unique functions or properties, upon which national security and economic prosperity depend, the supply of which could be restricted by internal or external forces, and for which there are no viable alternatives**. A subset of strategic materials, those deemed critical, are those facing a higher risk of supply disruption.

Using this definition then, the mining of strategic materials is a subset of the hard rock mining industry, which is distinct from mining for soft rock such as coal. In defining the strategic materials industry, this study considered not only mining, but also the range of downstream firms that refine, smelt, and further process and manufacture products containing strategic materials. As most of the strategic materials discussed are also metals, the term metals will at times be used interchangeably with mineral and/or strategic materials.

Why Are Strategic Materials Important?

A familiar phrase in the extraction industry is “If you can’t grow it, you must mine it.”[8] Minerals form the backbone of the modern world, with metals and other minerals providing the basic materials for our buildings, our transportation, and our consumer goods. As technology continues to advance and we learn more about the properties of individual elements, we discover new uses for minerals. The result is that today we use more of the periodic table than ever before. This has been a boon for national defense, as many newly-utilized elements confer properties on our defense applications that afford us considerable advantages over our adversaries. Minerals with unique properties have been put to use in renewable energy technologies as well as in our high-tech consumer goods such as smartphones and mobile devices. Just as we have come to depend on the advanced technologies that rely on these materials in our daily lives, so too has the DoD come to rely on the advanced defense technologies that are made possible by these materials. It is therefore essential to ensure secure access to the kinds of minerals needed to maintain military superiority.

Not all elements are created equal, however, and not all are abundant across the globe. Some, such as copper, are found in the U.S. in sufficient quantities to supply most current domestic needs (and as such are not considered “strategic” for the purposes of this study). For others, however, the U.S. is dependent on imports - either because they are not present in the U.S. or because U.S. deposits are not economically feasible to mine. In the case of rare earth elements (REEs) for example, global prices remain too low to make domestic extraction attempts economically feasible, particularly compared to hard rock mining in China with its lower labor costs and more lax environmental regulations. Mining is a hugely expensive undertaking, and new mines face years, if not decades, of permitting and regulatory hurdles before beginning operations. Prices for rare earths would need to rise to entice capital into the industry in the U.S. For the moment DoD demand for rare earths, although critical, is too small to provide the “pull” factor needed to bring new entrants into the field and make their extraction economically viable.

Market and Industry Overview

Domestic

The hard rock mining sector in the U.S. employs approximately 186,000 in just over 7,000 mining establishments.[9] The U.S. Metals and Mining Industry had revenues of $116.3 billion in 2015, which represented a drop of more than 15 percent over the last five years.[10] Most of this shrinkage can be attributed to the decline in mineral prices following the slowdown in China’s growth rate. MarketLine, a business information group, forecasts that the industry will see an annual growth rate of approximately 5.7 percent from 2015 through 2020 based on moderate growth in global commodity prices and the construction sector.[11] In 2015, U.S. revenues of $116.3 billion accounted for 6.6 percent of the global metals and mining industry value of $1.75 trillion. Asia-Pacific accounted for $1.17 trillion or 66.7 percent. Europe accounted for $255 billion, and the rest of the world accounted for $211 billion of value.[12]

Downstream sectors in the strategic materials industry in the United States have fallen behind the rest of the world. The top five producers of copper in the world in descending order are Chile, China, Peru, United States, and Australia; yet in considering smelter capacity, the U.S. ranks 9th behind China, Chile, Japan, Russia and India. According to the International Copper Study Group (ICSG) in 2016, of the top twenty smelter plants in the world by capacity, China has seven; the U.S. has none.[13]

According to the 2016 U.S. Geological Survey (USGS) Net Reliance Chart (Appendix C), the U.S. is currently 100 percent reliant on imports for twenty minerals. China is the main source for ten of them. What prevents the U.S. from developing domestic supplies? The domestic hard rock mining industry faces serious challenges due to price volatility, lengthy permitting processes, and the financial challenges to bringing new capacities online.

Price volatility within the hard rock industry can largely be attributed to China's consumption and export habits and its control of the mining and production of several strategic materials. China's GDP growth rate has averaged nearly 10 percent annually from 1989 to 2017, fueling a construction boom and increasing demand for both primary metals and by-product metals. The technology boom also added to the demand for strategic materials, which culminated in all-time high prices for copper and REEs in 2011. As China's GDP growth rate slowed, demand for metals and by-products fell, leaving many mining operations heavily leveraged. The corresponding drop in prices contributed to the closure of the only domestic REE mining operation at Mountain Pass, California, made it less feasible to start new REE operations in the U.S., and left China as the primary source of REE and other strategic materials.

Permitting continues to be a major disincentive to developing new mining resources in the United States. SNL Metals and Mining, a division of S&P Global Market Intelligence, conducted a market research analysis in 2015 commissioned by the American Mining Association and focused on the permitting of mines. The report revealed that it takes an average of seven to ten years for the permitting process to open a mine to be completed in the United States versus an average of two years for Canada and Australia, two countries with very similar stringent environmental regulations.[14] The report concluded that delays in permitting make stakeholders less likely to invest in exploration projects and "puts the security of the country's mineral supply at risk."[15] The report concluded that permitting delays have caused the share of global metals mining investment dollars attracted by the United States to drop from over 20 percent in the mid-1990s to approximately 7 percent in 2015.[16]

The cost of mining in the United States is another challenge hindering further development of domestic strategic materials extraction capabilities. A mine must remain open for many decades to earn a profit and justify the massive capital expenditures required for exploration, permitting, and metallurgical process development. The huge capital investment required limits new entry into the strategic material mining business; opening a mine and processing plant can cost anywhere from $500 million to $900 million before the first dollar is earned.[17] Price volatility means that even after a significant investment and successful production, the cost of extracting and processing the material could exceed the market price of the material. This is precisely what happened to Molycorp after it invested $1.5 billion in the Mountain Pass mine just before the drop in REE prices.[18]

Even after an initial capital investment, there are numerous costs associated with the operation of a mine. In the U.S., labor costs for hourly and salaried personnel account for approximately 50 percent of a mine's operating costs.[19] The price differential between mine worker salaries in the U.S. and other countries makes it difficult for the U.S. to compete globally. While U.S. salaries are comparable to those in Canada, the UK, Australia, and the EU, they are a great deal higher than those in less developed countries. The average U.S. salary can be ten to twenty times higher than the salaries paid in less developed countries such as China.[20]

The triple threats of price volatility, permitting delays, and the capital-intensive nature of mining have led to a void in the domestic mining and production of strategic materials. Despite this, the U.S. has never yet faced a critical lack of strategic materials. It has thus far been able to acquire what it could not produce domestically through trade with other countries. Although the USGS reported that U.S. dependence on foreign sources for raw and processed mineral materials increased slightly in 2016, U.S. trading partners, including China, continue to find it in their interest to sell these materials in the U.S. market.[21]

International

China dominates over two-thirds of world mining production overall, giving it considerable power to influence market conditions by controlling production or export quantities. Under the status quo, the U.S. could continue to source strategic materials from China at low cost; it remains in the interest of both countries to maintain trade flows. Yet China demonstrated in 2010 its willingness to use strategic materials as a political tool when it cut off REE supplies to Japan following a dispute over contested waters in the East China Sea. Deterioration in the U.S.-China bilateral relationship over any number of issues, such as the South China Sea, installation of anti-ballistic missile shields in South Korea, or trade imbalances, could similarly endanger that access.

Although China remains a sole source for scandium and currently provides over 90 percent of global production of REEs, the U.S. has healthy trading relationships with Canada, South Africa, Brazil, Chile, and Australia for other strategic materials. The U.S. is able to obtain from Canada 100 percent of its needed cesium and rubidium, which are used primarily in the petroleum industry. Brazil and Canada provide 100 percent of U.S. niobium requirements for its aerospace industry. South Africa and Brazil provide 100 percent of U.S. tantalum requirements and 91 percent of U.S. titanium requirements used by the U.S. military and the aerospace industry.[22] Other excellent trading partners include Chile and Australia, primarily due to their healthy mining industries and future potential. Both have potential for REE production,[23] and Chile is a major supplier of lithium.[24] So while the U.S. must continue to rely on China for some strategic materials, it has options that enable it to access others elsewhere.

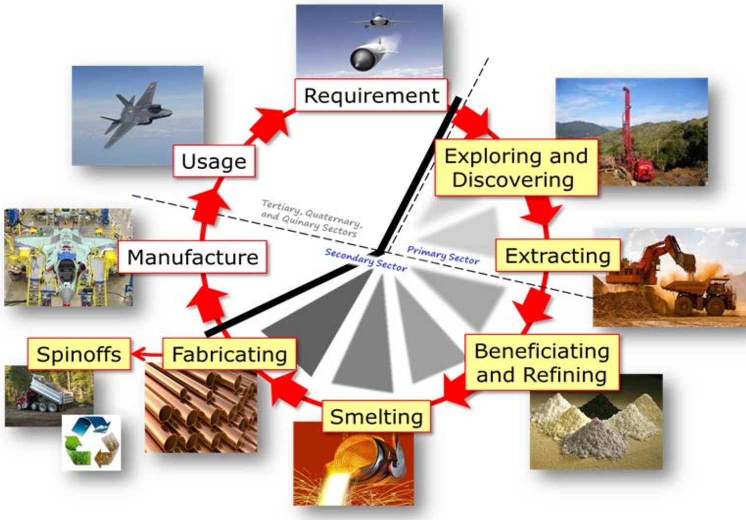
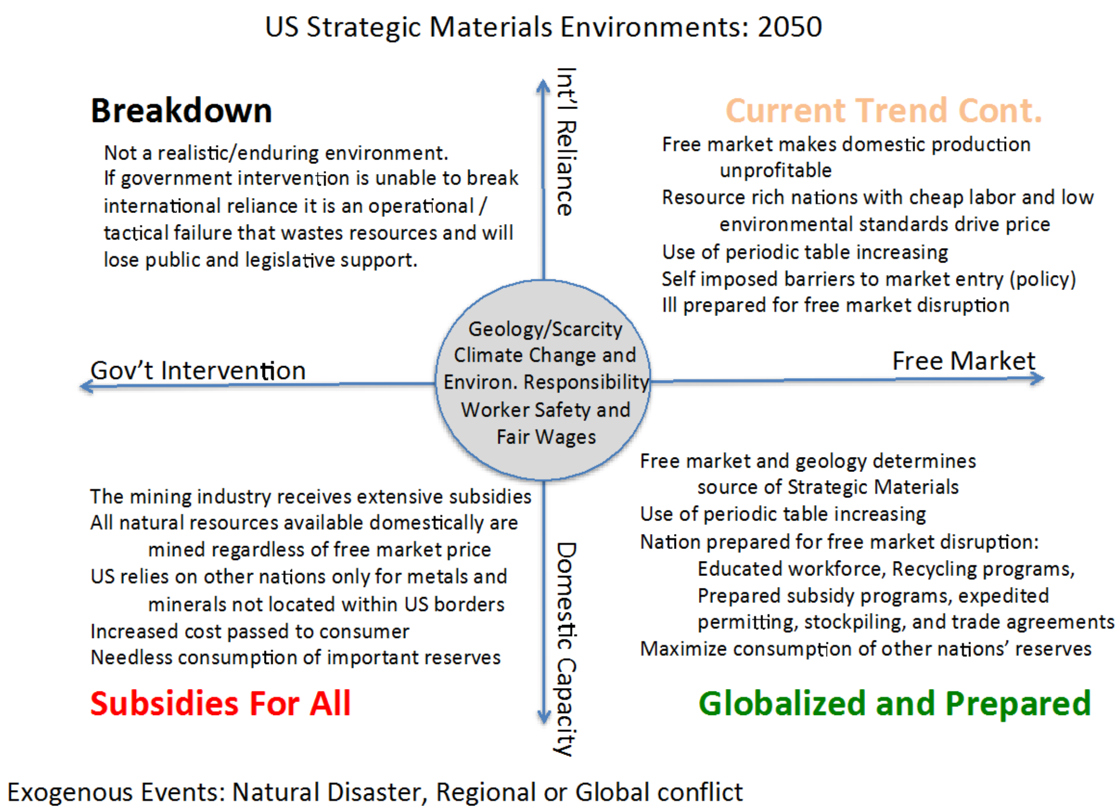


Figure 1 – Strategic Materials Industry Cycle[25]

Strategy for Securing Strategic Materials

Such is the current situation with regard to strategic materials. Yet what will the future bring, and how can the U.S. ensure access to these materials over the next five to fifty years? While it is impossible to know what the next fifty years will bring, a strategic evaluation of possible future scenarios can help steer the U.S. in the right direction to ensure minerals security in the long run. This paper uses the Shell 2 axis model of scenario planning to feed into an Ascher-Overholt model to create a portfolio of strategies.

The following illustration depicts four possible future scenarios. The horizontal axis represents potential U.S. government actions: intervention in the strategic materials market versus permitting free market forces to act unimpeded. The vertical axis represents U.S. reliance on imports of strategic materials versus U.S. reliance on domestic production. Each quadrant represents a different possible future scenario, with the circle in the center representing core elements likely to be common to all future scenarios.



Core Environment: Elements Central to Any Potential Future

The periodic table is an organized and structured way to represent an otherwise disorganized reality. Elements are distributed haphazardly across the crust of the earth. A volcano millions of years ago may have left a rich deposit in the middle of a modern desert while the collision of tectonic plates may have pushed another deposit 13,000 feet up into a mountain range. One nation may have an abundance of one element, and a dearth of another. The sprinkling of resources throughout the globe in varying concentrations is a strategic reality, and therefore drives U.S. strategy. Not everything the U. S. needs can be found within its borders, and the U.S. must therefore engage in international trade to fill commercial and military requirements. Such reliance on trade brings with it risk that can be mitigated through diversified international trade and efficient resource use.

The United States has come through the industrial revolution and into the modern age with an understanding of environmental stewardship and the regulation required to care for the land, air, and water of this nation. The extraction and beneficiation of strategic materials must not come at the cost of environmental degradation. Central to the strategic material resource strategy is continued observation of standards to safeguard the environment and ensure the future health and prosperity of the nation.

The American worker is the foundation of American prosperity. High productivity, innovation, wages, and standards of safety define the industrial workforce. Those standards are at the core of U.S. resource strategy and must not be compromised to compete with other nations' unsafe, underpaid, and less productive human capital. Continued investment to increase productivity, innovation and safety are the best methods to compete on the global free market and ensure a high standard of living within the U.S.

Preferred Environment (Free Market with Domestic Capacity)

The geology outlined in the core environment drives a globalized approach to resource strategy. The free market responds to the realities of geology and the economics of inexpensive labor and lax environmental controls. The resulting trend over the last decade within the U.S. mining industry has been decreasing commodity prices, unprofitability and a shrinking sector. The free market has not failed to meet the needs of the United States, but the United States has failed to prepare for the possibility of market failure or disruption.

Market disruption can result from changes in supply or demand. Supply can be impacted by natural disaster, conflict, trade agreements, and new reserve discovery. Demand can be impacted by conflict, trade agreements, new technology and use, the discovery of suitable substitutes, or the expansion of existing use. The basic resource strategy of the U.S. must focus on the possibility of decreased supply or increased demand and be prepared for the possibility that the free market may not always be able to meet the nation's resource needs.

Continued reliance on the free market allows the U.S. to consume the resources of other nations producing at a lower price, while preserving domestic reserves for later consumption. Over-reliance on this principle, however, could leave the nation vulnerable to market disruption. A comprehensive resource strategy recognizes the realities of geology, the importance of environmental stewardship, the rights of the American worker, the machinations of the free market, and U.S. vulnerability to market disruption. Therefore, staying on the path of globalization and preparation requires vigilance and a hedging strategy.

To be prepared in the event of free market disruption, a strategic hedge must comprise: (1) an educated workforce capable of operating in the mining industry; (2) Government incentive programs to bring critical domestic production on line; (3) policy that protects the environment while expediting the permitting process; (4) recycling/secondary supply programs that take advantage of resources found in consumer products; (5) a classified stockpile program that takes advantage of low commodity prices; (6) partnerships with multiple nations, focusing on supply chain diversity for strategic materials; and (7) a focus on automation and innovation.

The United States must reorganize agencies to effectively monitor strategic materials markets and manage preparation efforts. That responsibility can be assigned to the USGS, DoD, the Department of Commerce (DOC), or the Department of the Interior

(DoI). If the strategic materials environment drifts too far toward international reliance or if preparation turns into over-incentivizing domestic production to the point of free market disruption, there must be a single agency to act as a gatekeeper. In response to over-reliance on foreign supply compounded by market disruption, this gatekeeper must be able to implement elements of the preparation outlined in the hedging strategy. Conversely, if U.S. government intervention disrupts the free market, that same agency must put strategy back on track to rely on globalization while still preparing for free market failure.

Components of Minerals and Metals Security

The components of a strategic hedge must include near-, medium-, and long-term actions. As a comprehensive plan, many of the components will need to be implemented simultaneously. Therefore, the following discussion does not prioritize each item, but views them collectively as a package of actions designed to lead to long-term minerals security.

Senate Bill 145 and House of Representatives Bill 520

Senator Heller (R-NV) and Representative Amodei (R-NV) introduced Senate Bill 145 (S.145) and House of Representatives Bill 520 (H.R.520) to the 115th Congress on January 12-13, 2017.[26] These bills are identical and share the name, the "National Strategic and Critical Minerals Act."[27] The purpose of the Act is "to require the Secretary of the Interior and the Secretary of Agriculture to more efficiently develop domestic sources of the minerals and mineral materials of strategic and critical importance to the economic and national security and manufacturing competitiveness of the U.S., and for other purposes."[28] Similar legislation has passed the House of Representatives in the past, [29] but has never made it out of the Senate. The National Strategic and Critical Minerals Act proposes changes to three critical areas of the Strategic Materials Industry. The Act offers a comprehensive definition of strategic materials, it recommends time limits for exploration and mine permits, and it proposes the idea of a lead agency.

S.145 and H.R.520 define strategic and critical minerals as those minerals necessary for "…national defense and national security requirements; for the energy infrastructure of the U.S. including pipelines, refining capacity, electrical power generation and transmission; for renewable energy production; to support domestic manufacturing, agriculture, housing, telecommunications, healthcare, and transportation infrastructure; and for the economic security of, and balance of trade in, the U.S."[30] *We welcome a government-wide definition to eliminate confusion over issues of governance, resource allocation, and foreign policy.*

The proposals also establish a 30-month time limit for the completion of all permitting processes required for exploration and extraction.[31] This is long overdue. U.S. policies with regard to permitting, many intended to protect the environment, have created high barriers to investment in the Strategic Materials Industry. SNL Metals and Mining, a market intelligence firm, conducted research in 2015 concluding that permitting delays have caused the share of global metals mining investment dollars attracted by the U.S. to drop from over 20 percent in the mid-1990s to approximately 7 percent in 2015.[32] *The implementation of the proposed time limit provisions will improve the competitive position of the U.S. industry, which has been severely hampered by the long time frames required to fulfill regulatory requirements and complete the permitting processes to open a new mine.*

Finally, the legislation proposes to identify a lead agency with primary responsibility for issuing mineral exploration and mine permits for a project.[33] However, the Act does not specify a permanent agency to fulfill this role, which we suggest could counteract the efficiencies sought in this legislation. *Consequently, we recommend that the National Strategic and Critical Minerals Act be amended to identify the Department of the Interior (DOI) as the permanent lead agency for the purposes of this Act in order to achieve the desired improvement in permitting efficiencies*. The National Strategic and Critical Minerals Act should also be amended to allow the DOI a one-year period to study and determine the best governance structure for permitting in the industry that can rationalize federal, state, local, and tribal regulations, and then report back to Congress with the results. This governance structure should incorporate the inputs of the various stakeholders that have interests in the Strategic Materials Industry.

H.R. 1407 – Materials Essential to American Leadership and Security (METALS) Act

H.R. 1407 provides the capital resources for the U.S. to develop a domestic industrial base for the production of strategic and critical materials. *We recommend amending H.R. 1407 to allow the use of the Strategic Material Investment Fund to cover exploration and R&D for downstream activities related to the exploitation of strategic materials.* Use of the Strategic Material Funds for investment across the industry will provide U.S. mining with capital required to expedite operations and provide extracted and processed material sooner. The secondary supply system (recycling) requires additional research and development but will provide the U.S. with the near-term capability for resources while the long term (extraction through processing) comes online.

Currently, H.R. 1407 authorizes repayment of the loans to the Strategic Investment Fund no later than five years. *The length of these loans should be extended to up fifteen years.* This adjustment is required based on the 7 to 10 year average timeframe to bring a mine from exploration to extraction in the U.S., as well as on the time to reach profitability. *The terms of the loan should be determined by a tiered system based on need by the lead agency.*

Defense Production Act of 1950

The U.S. government can also utilize Title III authority of the Defense Production Act of 1950 (DPA) to incentivize the strategic materials industry. This authority permits incentives to the industry by creating or supporting production capacity in critical and strategic materials required for national defense purposes. These incentives can include direct subsidies, purchase commitments, and loans or loan guarantees. Since various strategic materials and rare earth elements are required in many critical defense technologies, using the DPA would be appropriate. The danger in direct subsidies lies with the potential for distorting the market and supporting companies that may never become viable. The counter-argument is that given the favorable economics of mining in lower-cost, less regulated jurisdictions, the mining and processing of certain strategic materials might never become competitive without government support and might always require some sort of intervention. Yet as a hedge against potential disruptions in supply, some kind of direct support to industries that could eventually mine and process the strategic materials needed for national security purposes may be needed. The critical question is whether to hedge or not. Incentives such as this are a hard sell in the absence of a crisis. However, should a crisis arise, it will already be too late.

Education

The American worker is the foundation of American prosperity. For the mining industry, investing in the American worker's education can increase productivity, spur innovation, and foster safety in the workplace. Yet, despite the fact that strategic materials production in the U.S. was a $74.6 billion industry in 2016[34], the industry still faces a number of challenges in ensuring access to an educated workforce in sufficient numbers. These challenges arise from low commodity prices, unprofitability, increased environmental regulation, and a poor public image of the mining industry. The industry further suffers from fluctuations in employment due to shifts in profitability and the industry's cyclical nature. This uncertainty of employment, coupled with mining's image problem, has pushed much of its future workforce to other fields of endeavor. This is unfortunate, as the workforce of the U.S. mining industry has always been a competitive advantage over foreign competition.

The federal government has worked with states since 2013 to improve STEM education, yet the prospects for improving workforce readiness for these jobs will require sustained investment over the long-term. With the Department of Education reporting that 50 percent of U.S. high schools do not offer calculus, 27 percent do not offer physics, and only one quarter are teaching computer programming,[35] the prospects for a future U.S. supply of workers in these fields look grim. *In order to sustain a well-educated and effectively trained workforce to support the U.S. mining industry, the U.S. government must continue its investment in science, technology, engineering and math (STEM) education, employment opportunities, and related vocational training programs.* This can include scholarships for qualified students to pursue degrees in STEM fields; postgraduate programs for industry-related research and development; and postdoctoral research grants that further develop education and employment opportunities.

Encouraging U.S. government involvement in STEM education to support the mining industry is not an attempt to revive a lagging industry. In fact, according to the United States Department of Labor's Bureau of Statistics (BLS), there are currently 8,300 mining and geological engineers employed in the United States,[36] and the demand for this expertise is projected to grow at a rate of 6 percent between 2014 and 2024.[37] However, mining firms fear that degree-producing programs and vocational training in mining-related studies are attracting fewer and fewer students, partly due to mining's negative image. Many universities have shuttered their mining degree programs. Yet access to domestically-sourced strategic materials can only continue if there is a supply of qualified applicants in science, engineering and technology fields.

Promoting STEM education will broadly expand overall opportunities in science and technology. Yet mining industry trade associations must also collaborate with universities and other educational institutions, as well as with federal and state Departments of Education to identify specific skills gaps. *By creating partnerships between the government, the U.S. mining industry, national trade associations, and academia, the industry can ensure that primary, secondary, and post-secondary education and vocational training programs align with domestic workforce demands.*

Additionally, luring qualified, potential employees to a particular industry is another task of its firms and trade associations. The mining industry would do well to address its poor public perception, which conjures up images of pick-ax yielding men with gritty faces, historic mining disasters, and environmental degradation, making the field unattractive to potential workers. However, modern mining is, in fact, a much more automated process that has become safer for both the workers and the environment. As technology and computer science evolves, the U.S. mining industry has made interdisciplinary advances in the use of autonomous vehicles, computer modeling that aids in the precise extraction of resources, and the development of advanced materials science that supports the continued modernization of society. These advances should be enticing to a contemporary workforce, but require a certain level of technical expertise. With fewer students interested in science, engineering and math, it is in the government's interest to invest in this problem. Yet while the U.S. government can support STEM education, it is the responsibility of the industry to address its own history and perception issues to help update its public image.

Increasing Secondary Supply - Recycling

China has cornered the market for several strategic materials including rare earths, setting prices, imposing export quotas, and playing by its own rules. To counter China's leverage over the market and mitigate the impact of market distortions, recycling strategic materials and rare earth metals from used products can increase secondary supply to reduce the need for foreign sources. A key component to the basic strategy, recycling takes advantage of resources found in consumer products and can give the United States a strategic materials advantage. Actions to increase U.S. resiliency should be aimed at improved efficiency of the use and recovery of materials from waste and scrap.[38]

Given the importance of these elements to national security and technological advances, governments worldwide are funding research to make recycling a viable option. *For near-term action, the U.S. government should conduct research and development on collection and recycling methodologies in order to produce an organic secondary supply of strategic materials. For mid-to-long term action, the U.S.*

government should incentivize organizations to cultivate a shift from a consumable society to a reusable society.

Each year tens of millions of products containing scarce and valuable strategic materials are thrown away. While new innovations are still needed to economically extract some of the strategic materials found in many consumer, defense, and industrial products, recycling scrap materials and discarded products may eventually help stabilize global demand as a secondary source of strategic materials. Recycling is not only beneficial to reduce the digital landfills of the world, but is also advantageous in that it can reduce the pressure on our natural resources and lessen mining production quotas in order to close the gap between supply and demand.[39] But recycling strategic elements is not as simple as recycling paper or plastic. As products and parts get lighter and leaner, so too do the amounts of material used. As such, breaking down superalloys and retrieving REEs from unwanted or unusable products is a complex process. It is likely that with continued research and development, recycling can reduce our dependence on foreign sources of strategic materials while helping to preserve the environment by reducing the demand for newly-mined minerals and slowing the growth of our landfills.

Near-Term

The United States is a leading investor and researcher in recycling technology. The Department of Energy's Critical Materials Institute (CMI) focuses on technologies that make better use of materials and eliminate the need for materials that are subject to supply disruptions. Recycling has been a key focus for the CMI team lead, Ames Laboratory. CMI is testing supercritical carbon dioxide, ionic liquids, and electrochemical methods as strategies for improving the prospects of recycling rare earths and superalloys.[40] Recycling superalloys results in the need for less raw material. Most superalloys retain their properties when recycled back into the original melt at the smelter, making them excellent candidates for secondary supply. The components and scrap of superalloys only have to be re-smeltered, which is estimated to be two to 10 times more energy efficient than smelting virgin ores.[41] Additionally, ore extraction represents seven percent of the world's energy consumption and contributes to global carbon emissions and climate change.[42] Since metals can be recycled many times, this reduces the need for more extraction, especially as ore grades continue to decline.

In order to make recycling mainstream, the life-cycle price of recycling must be considered for each individual element. Not all elements are created or recycled equally. Therefore, some REEs and superalloys require substantial upfront capital investment in order to generate and sustain the most efficient and cost-effective recycling methods. According to the 2017 United States Geological Survey (USGS) Commodities Report, the U.S. is reliant on foreign sources for 81percent of rhenium and 100percent of tantalum and yttrium.[43] These elements are vital building blocks for superalloys used in the production of aircraft engines. One option to ensure their availability is to increase a secondary supply by recycling the superalloys through the reclamation of scrap and end-of-use parts. In 2015, Defense Logistics Agency (DLA)-Strategic Materials created the Strategic Material Recovery and Reuse Program and worked with their Disposition Services office and the Air Force to address approximately 60,000 pounds of Pratt & Whitney engine parts and a backlog of items in the DLA warehouse.[44] DLA targeted precious metal recovery and aerospace recyclable materials. The program has been highly effective with funds received from recycling output used to support stockpiling operations, including for the purchase of inventory. The ability of government agencies to reap direct financial benefits from recycling efforts is a key incentive to expanding recycling in the U.S.

In 2008, due to a perceived rhenium supply shortage prices peaked at $4,717/pound.[45] To address rising costs General Electric (GE) implemented several measures, including recycling waste alloy from the casting process and expanding its end-of-life engine recycling program to include its user base.[46] These reclamation efforts reduced the amount of first supply (newly mined) rhenium GE required and reduced the impact of future rhenium price fluctuations. Additionally, in 2013 the United Nations Environmental Program estimated that greater than 50percent of end-of-life products containing rhenium are recycled.[47] The high levels of recycling may have contributed to the fall in the market price of rhenium to $1,025/pound, even though demand for superalloys containing rhenium has been steadily increasing over the past five years. [48]

Mid-to-Long Term

Increasing the secondary supply of strategic materials is essential for maximizing the current supply and reducing dependence on foreign production. Under current conditions, however, it is difficult for the U.S. to do more. REEs and super-alloys are not being recycled in large quantities today, but they could be if recycling were mandated, incentivized, or if higher prices for rare earth elements made recycling feasible. Ironically, the one situation everyone is trying to avoid may be what the recycling community needs in order to gain momentum: the advent of another strategic materials crisis. Whether by deliberate contraction of supply or expansion of demand, a crisis might be the catalyst for continuous global investment and research – making recycling of these elements a sustainable first choice over complete foreign dependence. [49]

Until economics, legislation, and the demand for rare earths catch up with each other, further research and development must be conducted to produce more efficient and resourceful methods of recycling in order to achieve a sustainable secondary source. [50] This can largely be realized by government incentives to promote efficient, fully integrated recycling initiatives. The U.S. government can increase strategic materials recycling by providing incentives to encourage private firms to recycle and by enforcing recycling quotas. An incentive system similar to the deposit refund on soda cans could spur consumers to return used computers, hard drives, and other consumable devices.[51] Some companies already do this; for example, Hewlett Packard (HP) implements this policy on any HP product, recycling 2.8 billion pounds of products since 1987.[52] Despite the monetary investment required, recycling provides long-term profit and sustainability well worth the upfront cost, and can be an important element of a hedging strategy to ensure access to strategic materials. Furthermore, although products are currently designed to maximize maintainability, the future of product design should also focus on reclamation, which would prove beneficial from both an environmental and supply chain perspective. Incorporating and emphasizing end-of-use opportunities and design for reclamation within current acquisition plans will develop a cradle-to-cradle culture, as material is not disposed of, but reclaimed. [53]

Stockpiling

Stockpiling is the most basic of hedging options available to defend against free market disruption. The U.S. currently maintains a stockpile of several materials, which is managed by the Defense Logistics Agency (DLA). Three aspects of stockpiling need revision to enhance support of the hedging strategy: quantity determination, classification, greater flexibility to manage the stockpile.

The current National Defense Strategy (NDS) calls for maintaining a stockpile of material intended to meet national security needs based on scenario of a one-year conflict followed by a three-year reconstruction period.[54] The basis of this scenario is outdated and not supported by our historical wars. U.S. engagement in Afghanistan and Iraq continues after more than a decade. Both the Vietnam War and the Korean War far exceeded a one-year conflict range. Additionally, the task of determining how much of an element to stockpile has proven challenging for military planners. The National Materials Advisory Board (NMAB) identified that, "the DOD appears to not fully understand its need for specific material or to have adequate information on their supply."[55] Rather than determine stockpile needs based on the current arbitrary scenario, *we recommend that the U.S government determine the actual stockpile quantity of a strategic material based on the length of time required to bring online domestic production or a secondary supply.*

DLA produces the Strategic and Critical Materials Report on Stockpile Requirements every two years and an annual Materials Plan (what to procure & sell) and Operations Report (annual review of actions). The Stockpile requirements report and Materials Plans contain both unclassified and classified portions. *We recommend completely classifying the contents and quantities of the stockpile to prevent adversaries from exploiting the information on the list.* China has proven that it is willing to use its monopoly of REE for political means.[56] Denying the Chinese and other potential hostile actors this information serves U.S. national interests. Classification further protects the mining industry from free market disruption due to artificial demand signals generated by stockpile purchasing. Opponents to classification would argue that this may skew the market; however, if stockpile purchases are gradual and discreet it should minimize disruption.

Finally, enabling DLA more flexibility to manage the stockpile would create a more economic and efficient stockpile. Currently, Congress provides authority for stockpile content, purchase timelines, and National Stockpile Transaction Fund levels that can be spent in the National Defense Authorization Act (NDAA) each year. *In order to effectively and economically address stockpile needs we recommend delegating authority to buy and sell strategic materials to DLA.* Announcing this information in the NDAA highlights the classification concern above, but also results in at least a 2-year delay between when DLA initially identifies a mineral requirement to acquire or sell until they can actually execute the strategy. In fact, for the most recent authority to purchase, it took five years between when first identified and Congress approved. Strategic material markets fluctuate and to manage the stockpile efficiently, DLA needs to be able to take advantage of the markets when necessary.

International Partners

The United States must continue to build and maintain strong trade relationships with resource-rich nations. As a material rises in strategic significance, the supply chain diversity must also increase. The nation cannot afford to rely on a potential adversary for 100 percent of a commodity that is important for national defense. However, the realities of geology and the free market may mean the U.S. has to rely on exclusively foreign sources. It is essential that the U.S. foster strong trading relationships and encourage oversea investments with these reliable trading partners to maintain a competitive global strategic material industry. *Multilateral and bilateral trade agreements with historically allied nations and emerging democracies remain an effective hedge against single points of trade failure and market disruption.*

Technology and Automation

Since 1950, research and exploration in the U.S. mining industry has greatly benefited from technology and automation. Many mineral discoveries were made because of geophysical and geochemical technologies developed by both the mining industry and the U.S. government. However, since the 1990s the U.S. mining industry has invested less in development of new, mining-specific technology and has instead applied technology from other industries such as the medical and defense industries (tomographic imaging, GPS) to mineral exploration.[57] These technologies have led to improvements in safety and can open up new possibilities for the industry in terms of exploring currently inaccessible resources under the sea or in space.

In 2002, more than 7,000 Chinese miners died in accidents; by 2014 that number fell to 931.[58] In comparison, the United States had nine coal mining deaths in 2016.[59] The low numbers of fatalities in the U.S. is due in large part to technology and automation. Examples of these technologies include fatigue monitoring, automated underground mining, and proximity and collision warning systems. Using automation to conduct underground mining removes people from the most dangerous parts of mine operations.[60] These technologies not only saves lives but lower costs related to injuries, fatalities, and lost productivity, while supporting the core strategy by increasing the productivity of the foundation of American prosperity, the American worker. Furthermore, automation's high cost of capital investment is offset in the long run by its cost savings in reduction in payroll and benefits. This technology also improves efficiency and productivity by allowing for 24-hour operations by using unmanned vehicles. These technologies have potential for use in deep sea mining and space exploration.

Encouraging U.S. government involvement in the research and development of new technology for exploration, mineral processing, and big data will support a minerals security strategy by preparing the U.S. for market disruptions and helping to eliminate over-reliance on foreign imports. These technologies look to the future by developing the capability to explore the remote regions of the earth, the deep sea, and space. Furthermore, new technology is required to process low-grade ores, as well as to re-examine the resources that may be found in existing tailings. Key to research and development is the establishment of a secure national database for mineralized areas, exploration of aerial technology for mining, and production and development of mining.

Conclusions

This survey has attempted to examine the strategic materials industry as a whole, from exploration and extraction through the downstream processing of minerals and metals. These materials are vital to U.S. national security, yet the country remains vulnerable to supply shocks due to a lack of domestic supply capable of satisfying U.S. demand. While some might propose direct government support to the industry to create a domestic supply of the strategic materials the U.S. lacks, the Strategic Materials Industry Study prefers a more free market approach. We propose that the U.S. continue to source strategic materials from trading partners, preserving domestic reserves until such time as their development becomes economic.

Yet the government also needs to recognize the vulnerabilities that arise from such a strategy, and hedge against supply risks by implementing our proposed recommendations to enable the U.S. to tap into those currently uneconomic reserves should the need arise. The U.S. needs to increase the readiness of its workforce to meet future supply challenges, pass legislation to support the more rapid development of a domestic strategic materials industry, from exploration through metals processing and manufacturing, improve access to a secondary supply of materials through recycling, and continue to conduct research and development to develop technologies to access currently inaccessible materials. In the meantime, the U.S. needs to address shortcomings in its stockpiling provisions and maintain adequate reserves of the most vulnerable strategic materials in quantities that can weather the initial stages of a supply crisis until U.S. production can come online. Taken as a whole, these measures will strengthen national security by ensuring the U.S. can source the materials that provide it with a competitive and strategic advantage.

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Appendix A: Glossary of Mining Terms

A

Acid mine drainage - Acidic run-off water from mine waste dumps and mill tailings ponds containing sulphide minerals. Also refers to ground water pumped to surface from mines.
Adit - An opening driven horizontally into the side of a mountain or hill for providing access to a mineral deposit.
Alloy - A compound of two or more metals.
Alluvium - Relatively recent deposits of sedimentary material laid down in river beds, flood plains, lakes, or at the base of mountain slopes. (adj. alluvial)
Alteration - Any physical or chemical change in a rock or mineral subsequent to its formation. Milder and more localized than metamorphism.
Anode - A rectangular plate of metal cast in a shape suitable for refining by the electrolytic process.
Anomaly - Any departure from the norm which may indicate the presence of mineralization in the underlying bedrock.
Assay - A chemical test performed on a sample of ores or minerals to determine the amount of valuable metals contained.
Assay map - Plan view of an area indicating assay values and locations of all samples taken on the property.

B

Back - The ceiling or roof of an underground opening.
Backfill - Waste material used to fill the void created by mining an orebody.
Banded iron formation - A bedded deposit of iron minerals.
Base metal - Any non-precious metal (eg. copper, lead, zinc, nickel, etc.)..
Bauxite - A rock made up of hydrous aluminum oxides; the most common aluminum ore.
Beneficiate - To concentrate or enrich; often applied to the preparation of iron ore for smelting.
Bio-leaching - A process for recovering metals from low-grade ores by dissolving them in solution, the dissolution being aided by bacterial action.
Blast furnace - A reaction vessel in which mixed charges of oxide ores, fluxes and fuels are blown with a continuous blast of hot air and oxygen-enriched air for the chemical reduction of metals to their metallic state.
Broken reserves - The ore in a mine which has been broken by blasting but which has not yet been transported to surface.
Bulk mining - Any large-scale, mechanized method of mining involving many thousands of tons of ore being brought to surface per day.
Bulk sample - A large sample of mineralized rock, frequently hundreds of tonnes, selected in such a manner as to be representative of the potential orebody being sampled. Used to determine metallurgical characteristics.
Byproduct - A secondary metal or mineral product recovered in the milling process.

C

Cage - The conveyance used to transport men and equipment between the surface and the mine levels.
Calcine - Name given to concentrate that is ready for smelting (i.e. the sulphur has been driven off by oxidation).
Cathode - A rectangular plate of metal, produced by electrolytic refining, which is melted into commercial shapes such as wirebars, billets, ingots, etc.
Chip sample - A method of sampling a rock exposure whereby a regular series of small chips of rock is broken off along a line across the face.
Complex ore - An ore containing a number of minerals of economic value. The term often implies that there are metallurgical difficulties in liberating and separating the valuable metals.
Concentrate - A fine, powdery product of the milling process containing a high percentage of valuable metal.
Concentrator - A milling plant that produces a concentrate of the valuable minerals or metals. Further treatment is required to recover the pure metal.
Conglomerate - A sedimentary rock consisting of rounded, water-worn pebbles or boulders cemented into a solid mass.
Crust - The outermost layer of the Earth; includes both continental and oceanic crust.
Cut value - Applies to assays that have been reduced to some arbitrary maximum to prevent erratic high values from inflating the average.

D

Development - Underground work carried out for the purpose of opening up a mineral deposit. Includes shaft sinking, crosscutting, drifting and raising.
Development drilling - drilling to establish accurate estimates of mineral reserves.
Dilution (mining) - Rock that is , by necessity, removed along with the ore in the mining process, subsequently lowering the grade of the ore.
Directional drilling - A method of drilling involving the use of stabilizers and wedges to direct the orientation of the hole.
Disseminated ore - Ore carrying small particles of valuable minerals spread more or less uniformly through the host rock.
Drawpoint - An underground opening at the bottom of a stope through which broken ore from the stope is extracted.
Drift - A horizontal underground opening that follows along the length of a vein or rock formation as opposed to a crosscut which crosses the rock formation.
Drill-indicated reserves - The size and quality of a potential orebody as suggested by widely spaced drill holes; more work is required before reserves can be classified as probable or proven.
Dump - A pile of broken rock or ore on surface.

E

Electrolysis - An electric current is passed through a solution containing dissolved metals, causing the metals to be deposited onto a cathode.
Electrolytic refining - The process of purifying metal ingots that are suspended as anodes in an electrolytic bath, alternated with refined sheets of the same metal which act as starters or cathodes.
EM survey - A geophysical survey method which measures the electromagnetic properties of rocks.
Exploration - Prospecting, sampling, mapping, diamond drilling and other work involved in searching for ore.

F

Fault - A break in the Earth's crust caused by tectonic forces which have moved the rock on one side with respect to the other.
Fissure - An extensive crack, break or fracture in rocks.
Float - Pieces of rock that have been broken off and moved from their original location by natural forces such as frost or glacial action.
Fold - Any bending or wrinkling of rock strata.
Footwall - The rock on the underside of a vein or ore structure.
Fracture - A break in the rock, the opening of which allows mineral-bearing solutions to enter. A "cross-fracture" is a minor break extending at more-or-less right angles to the direction of the principal fractures.

G

Galena - Lead sulphide, the most common ore mineral of lead.
Gamma - A unit of measurement of magnetic intensity.
Gangue - The worthless minerals in an ore deposit.
Geochemistry - The study of the chemical properties of rocks.
Geology - The science concerned with the study of the rocks which compose the Earth.
Geophysics - The study of the physical properties of rocks and minerals.
Geophysical survey - A scientific method of prospecting that measures the physical properties of rock formations. Common properties investigated include magnetism, specific gravity, electrical conductivity and radioactivity..
Glory hole - An open pit from which ore is extracted, especially where broken ore is passed to underground workings before being hoisted.
Gypsum - A sedimentary rock consisting of hydrated calcium sulphate.

H

Hoist - The machine used for raising and lowering the cage or other conveyance in a shaft.
Horse - A mass of waste rock lying within a vein or orebody.
Horst - An upfaulted block of rock.
Host rock - The rock surrounding an ore deposit.

Hydrometallurgy - The treatment of ore by wet processes, such as leaching, resulting in the solution of a metal and its subsequent recovery.

I

Industrial minerals - Non-metallic, non-fuel minerals used in the chemical and manufacturing industries. Examples are asbestos, gypsum, salt, graphite, mica, gravel, building stone and talc.
Intrusive - A body of igneous rock formed by the consolidation of magma intruded into other rocks, in contrast to lavas, which are extruded upon the surface.
Ion exchange - An exchange of ions in a crystal with irons in a solution. Used as a method for recovering valuable metals, such as uranium, from solution.

L

Leachable - Extractable by chemical solvents.
Leaching - A chemical process for the extraction of valuable minerals from ore; also, a natural process by which ground waters dissolve minerals, thus leaving the rock with a smaller proportion of some of the minerals than it contained originally.
Level - The horizontal openings on a working horizon in a mine; it is customary to work mines from a shaft, establishing levels at regular intervals, generally about 50 metres or more apart.
Lode - A mineral deposit in solid rock.

M

Map-staking - A form of claim-staking practiced in some jurisdictions whereby claims are staked by drawing lines around the claim on claim maps at a government office.
Metallurgy - The study of extracting metals from their ores.
Mill - A plant in which ore is treated and metals are recovered or prepared for smelting; also a revolving drum used for the grinding of ores in preparation for treatment.
Milling ore - Ore that contains sufficient valuable mineral to be treated by milling process.
Minable reserves - Ore reserves that are known to be extractable using a given mining plan.
Mineral - A naturally occurring homogeneous substance having definite physical properties and chemical composition and, if formed under favorable conditions, a definite crystal form.
Muck - Ore or rock that has been broken by blasting.
Muck sample - A representative piece of ore that is taken from a muck pile and then assayed to determine the grade of the pile.

N

Native metal - A metal occurring in nature in pure form, uncombined with other elements.

Net smelter return - A share of the net revenues generated from the sale of metal produced by a mine.

O

Open pit - A mine that is entirely on surface. Also referred to as open-cut or open-cast mine.
Ore - A mixture of ore minerals and gangue from which at least one of the metals can be extracted at a profit.
Ore pass - Vertical or inclined passage for the downward transfer of ore connecting a level with the hoisting shaft or a lower level.
Orebody - A natural concentration of valuable material that can be extracted and sold at a profit.
Ore Reserves - The calculated tonnage and grade of mineralization which can be extracted profitably; classified as possible, probable and proven according to the level of confidence that can be placed in the data.
Oreshoot - The portion, or length, of a vein or other structure that carries sufficient valuable minerals to be extracted profitably.
Outcrop - An exposure of rock or mineral deposit that can be seen on surface, that is, not covered by soil or water.
Oxidation - A chemical reaction caused by exposure to oxygen that results in a change in the chemical composition of a mineral.

P

Pig iron - Crude iron from a blast furnace.
Pillar - A block of solid ore or other rock left in place to structurally support the shaft, walls or roof of a mine.
Placer - A deposit of sand and gravel containing valuable metals such as gold, tin or diamonds.
Plate tectonics - A geological theory which postulates that the Earth's crust is made up of a number of rigid plates which collide, rub up against and spread out from one another.
Possible reserves - Valuable mineralization not sampled enough to accurately estimate its tonnage and grade, or even verify its existence. Also called "inferred reserves."
Potash - Potassium compounds mined for fertilizer and for use in the chemical industry.
Primary deposits - Valuable minerals deposited during the original period or periods of mineralization, as opposed to those deposited as a result of alteration or weathering.
Probable reserves - Valuable mineralization not sampled enough to accurately estimate the terms of tonnage and grade. Also called "indicated reserves."
Prospect - A mining property, the value of which has not been determined by exploration.
Proven reserves - Reserves that have been sampled extensively by closely spaced diamond drill holes and developed by underground workings in sufficient detail to render an accurate estimation of grade and tonnage. Also called "measured reserves.".
Pulp - Pulverized or ground ore in solution.

R

Rake - The trend of an orebody along the direction of its strike.
Rare earth elements - Relatively scarce minerals such as niobium and yttrium.
Reclamation - The restoration of a site after mining or exploration activity is completed.
Reconnaissance - A preliminary survey of ground.
Recovery - The percentage of valuable metal in the ore that is recovered by metallurgical treatment.
Refractory ore - Ore that resists the action of chemical reagents in the normal treatment processes and which may require pressure leaching or other means to effect the full recovery of the valuable minerals.
Replacement ore - Ore formed by a process during which certain minerals have passed into solution and have been carried away, while valuable minerals from the solution have been deposited in the place of those removed.
Resource - The calculated amount of material in a mineral deposit, based on limited drill information.
Royalty - An amount of money paid at regular intervals by the lessee or operator of an exploration or mining property to the owner of the ground. Generally based on a certain amount per tonne or a percentage of the total production or profits. Also, the fee paid for the right to use a patented process.
Run-of-mine - A term used loosely to describe ore of average grade.

S

Salting - The act of introducing metals or minerals into a deposit or samples, resulting in false assays. Done either by accident or with the intent of defrauding the public.
Sample - A small portion of rock or a mineral deposit taken so that the metal content can be determined by assaying.
Sampling - Selecting a fractional but representative part of a mineral deposit for analysis.
Scaling - The act of removing loose slabs of rock from the back and walls of an underground opening, usually done with a hand-held scaling bar or with a boom-mounted scaling hammer.
Secondary enrichment - Enrichment of a vein or mineral deposit by minerals that have been taken into solution from one part of the vein or adjacent rocks and redeposited in another.
Seismic prospecting - A geophysical method of prospecting, utilizing knowledge of the speed of reflected sound waves in rock.
Shaft - A vertical or inclined excavation in rock for the purpose of providing access to an orebody. Usually equipped with a hoist at the top, which lowers and raises a conveyance for handling workers and materials.
Shale - Sedimentary rock formed by the consolidation of mud or silt.
Shear or shearing - The deformation of rocks by lateral movement along innumerable parallel planes, generally resulting from pressure and producing such metamorphic structures as cleavage and schistosity.
Shoot - A concentration of mineral values; that part of a vein or zone carrying values of ore grade.

Slag - The vitreous mass separated from the fused metals in the smelting process.
Sludge - Rock cuttings from a diamond drill hole, sometimes used for assaying.
Strip mine - An open-pit mine, usually a coal mine, operated by removing overburden, excavating the coal seam, then returning the overburden.

T

Tailings - Material rejected from a mill after most of the recoverable valuable minerals have been extracted.
Tailings pond - A low-lying depression used to confine tailings, the prime function of which is to allow enough time for heavy metals to settle out or for cyanide to be destroyed before water is discharged into the local watershed.
Trench - A long, narrow excavation dug through overburden, or blasted out of rock, to expose a vein or ore structure.

V

Vein - A fissure, fault or crack in a rock filled by minerals that have travelled upwards from some deep source.

W

Waste - Unmineralized, or sometimes mineralized, rock that is not minable at a profit.

Y

Yield - The current annual dividend rate expressed as a percentage of the current market price of the stock.

Z

Zone - An area of distinct mineralization.
Zone of oxidation - The upper portion of an orebody that has been oxidized.

Source:
https://www.sec.gov/Archives/edgar/data/1165780/000116578003000001/glossary.htm

Appendix B: STRATMAT Definitions

House Resolution 520 (S.145) “National Strategic and Critical Minerals Production Act”	**House Resolution 1407** “METALS Act”	**Title 50 U.S.C. Section 98** “The Strategic and Critical Materials Stock Piling Act”
(a) Definition of Strategic and Critical Minerals.--In this section, the term ``strategic and critical minerals" means minerals that are necessary-- (1) for the national defense and national security requirements; (2) for the energy infrastructure of the United States, including-- (A) pipelines; (B) refining capacity; (C) electrical power generation/transmission; and (D) renewable energy production; (3) to support domestic manufacturing, agriculture, housing, telecommunications, healthcare, and transportation infrastructure; or (4) for the economic security of, and balance of trade in, the United States.	“Strategic and critical materials” means— (A) the lanthanide elements, yttrium, and scandium; (B) titanium and titanium alloys; (C) magnesium; (D) antimony; (E) tungsten; (F) uranium; (G) tantalum; (H) fluorspar; (I) lithium; (J) strontium; (K) vanadium; (L) steel— (i) with a maximum alloy content exceeding one or more of the following limits: (I) manganese, 1.65percent; (II) silicon, 0.60percent; or (III) copper, 0.60percent; or (ii) containing more than 0.25percent of any of the following elements: aluminum, chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten, or vanadium; (M) zirconium and zirconium base alloys; (N) metal alloys consisting of nickel, iron-nickel, and cobalt base alloys containing a total of other alloying metals (except iron) > 10percent; (O) thorium; and (P) any other materials determined to be materials critical to national security by the SMBP	(1) The term "strategic and critical materials" means materials that (A) would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency, and (B) are not found or produced in the United States in sufficient quantities to meet such need. (2) The term "national emergency" means a general declaration of emergency with respect to the national defense made by the President or by the Congress.

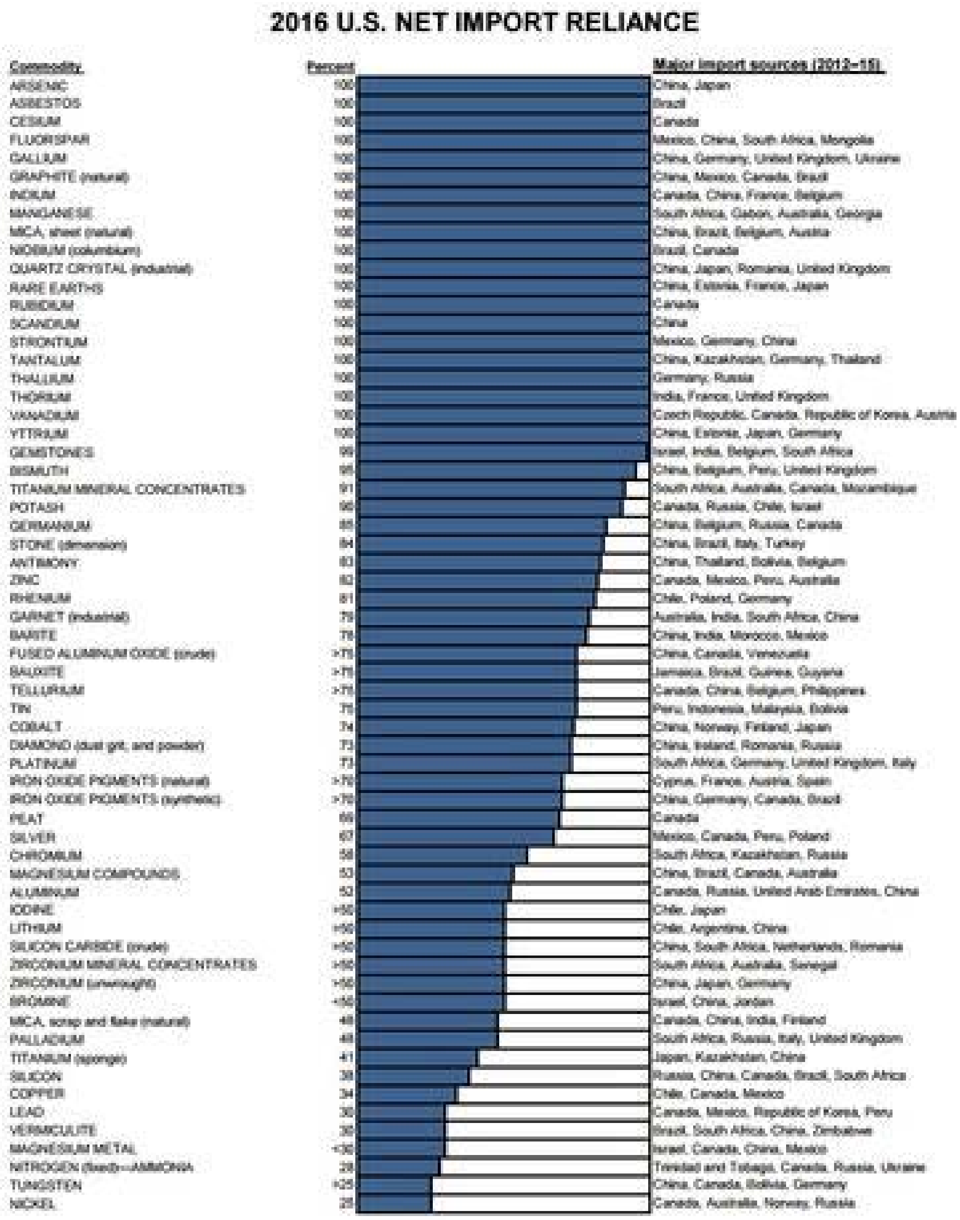
North American Industry Classification System Codes for Strategic Materials

- 2122 ... Metal Ore Mining
  - 21223 ... Copper, Nickel, Lead, and Zinc Mining
- 21311 ... Support Activities for Mining
  - 213114 ... Support Activities for Metal Mining
  - 213115 ... Support Activities for Nonmetallic Minerals (except Fuels) Mining
- 333313 ... Mining Machinery and Equipment Manufacturing
- 541330 ... Engineering Services (mining engineering services)
- 813910 ... Business associations (mining associations)

Standard Industrial Classification (SIC) Codes for Strategic Materials

- 1021 ... Copper Ore
- 1081 ... Metal mining services
- 1099 ... Miscellaneous Metal Ores, Not Elsewhere Classified
- 3295 ... Minerals and Earths, Grounded and Otherwise Treated
- 3532 ... Mining Machinery and Equipment, Except for Oil and Gas Field Machinery and Equipment

Appendix C: USGS Import Reliance Chart



Source: USGS https://www.usgs.gov/media/images/2016-us-net-import-reliance

Appendix D: The Role of China

China has become a significant factor in the strategic materials sector, even beyond the influence it exerts as a trading partner and as the geographical source of many critical elements. Specifically, China is engaged in its own global effort to acquire natural resources abroad, which has the potential to alter current markets and supply chains. China influences markets and supply chains in three significant ways: (1) acquiring on a large scale both developed and undeveloped sources of strategic materials in South America, Africa, Southeast Asia, and Australia; (2) leveraging its many mining firms (both state-owned and private), government support, and buying power as the largest global consumer to exert influence on major non-Chinese firms; (3) increasingly monopolizing downstream activities in strategic materials.

Since about 2000, China's economic explosion has led to greater and greater consumption of natural resources. Despite being the number one mining country in the world,[1] China is also a net metals and minerals importer. Between 2000-2010, China's consumption of copper tripled, its consumption of iron ore quintupled, and its intake of alumina and bauxite more than quintupled.[1] By 2003, China became more than 50 percent import-dependent for iron ore.[1] China's own natural resources, massive as they are, are not enough to sustain its current consumption levels, much less fuel a growth economy in the next few years. China must therefore look abroad to acquire additional national resources, and since 2000, it has done so on a massive scale. For example, by 2010, China accounted for 38 percent of global copper demand, 42 percent of aluminum demand, and similar proportions of many other metals.[1] Its biggest investment abroad is in Australia, where between 2005-2013 it invested $30 billion (only counting deals worth more than $100 million). Of that, 80 percent was directed to mining, and 50 percent of that to iron ore.[1] China likewise invested over $17 billion in mining deals in South America during the same period.[1] Africa, despite lower dollar investments from China, is second only to Australia as a source of minerals, and Chinese officials are pushing for more resource companies (both private and state-owned) to invest in Africa.[1]

China's investment in Africa is illustrative and to date has already been transformative. In 2009, China became Africa's leading trading partner.[1] By 2013, China was responsible for more than 15 percent of foreign direct investment in Africa.[1] Between 2006-2015, the number of major Chinese mineral processing facilities in Africa grew from 4 or 5 to over 120.[1] During that same period, China increased its mining presence in Africa from 3 countries to 22[1], and since 2015 has engaged at least three more.[1]

China's acquisitions throughout this time period have focused on base metals (primarily copper, bauxite, and iron ore to fuel its steel, construction, and aluminum industries), and uranium.[1] However, since 2012, its acquisitions of precious metals and minor metals have grown, reflecting the growing sophistication of Chinese industry and finance.[1] Some recent representative acquisitions include the purchase of one of the biggest uranium deposits in the world, located in Namibia,[1] the purchase of a controlling stake in an advanced project to exploit the massive Kamoa copper deposit in the Democratic Republic of Congo (DRC),[1] and the purchase of U.S.-based Freeport-McMoRan's interests in the holding company with interests in the DRC's Tenke Fungurume mine in the DRC.[1] The Tenke Fungurume Mine is the largest copper mine in the DRC and one of the world's largest copper and cobalt resources. In addition, by 2012 China had invested more than $1 billion in Zambia's copper industry.[1] Between 2011-2016, China initiated ten new coal, copper, gold, and platinum group metal (PGM) projects in South Africa.[1] Similar acquisitions in South America, Southeastern Asia, and Australia abound.

China also increasingly exerts influence over non-Chinese firms around the globe. Chinese steel firm Sinosteel recently extended a partnership with Australian giant Rio Tinto for iron ore from Australia itself.[1] Rio Tinto in effect acts as Sinosteel's operating agent, running the mine while China gets 100 percent of the iron ore. Just this year, Rio Tinto struck a partnership with Chinese state-owned entity Minmetals. The two companies "agreed to look for potential areas of future co-operation".[1] Minmetals had previously tried to buy Rio Tinto's Canadian iron ore business. Chinese firms are making frequent use of joint ventures or significant shareholder stakes in projects to influence where the product will go. Last year, Rio Tinto sold its 46.6 percent stake of the Simandou (Guinea) iron ore project to Chinalco, increasing the Chinese firms stake to 92.5 percent.[1] Simandou has been touted as the world's largest mining project, and would be the largest iron ore mine in Africa at least.

The project started out as a joint venture between the two firms. During the partnership, the Chinese put significant pressure on Rio Tinto to acquire a seat on its board of directors. In 2011, a consortium of Chinese steel firms (Baosteel Group Corp., Shougang Corp., Anshan Iron & Steel Group Corp., and Taiyuan Iron & Steel Group Co.) purchased a 15 percent share of Companhia Brasileira de Metalurgia e Mineracao (CBMM) for $1.95 billion.[1] The Brazilian CBMM is the world's largest niobium producer (around 85 percent of world production). The four firms had previously been CBMM's customers, and the deal represented the first time in its more than 75 year history that the family-owned business had sold part of its company. In addition to buying into former suppliers, Chinese firms also partner with other countries state-owned enterprises to ensure commodities are directed to China. The Ghana Bauxite Company, for example, nominally a state-owned enterprise of the Government of Ghana, is in fact 80 percent owned by the Chinese Bousai Minerals Group.[1]

Assessing the impact of these impressive investments, however, one does not conclude that China is currently in a position of strategic advantage in the mining and metals sector. "Chinese mining investment activity outside China remains mostly marginal. China's scramble for resources in Australia, Africa, and elsewhere involves minimal investment values despite rapid growth in recent years." The sheer volume of global mining investment coming from China still pales next to the shares taken by players from the United States, Canada, Australia, and other established sources."[1] For example, the USGS reports more than 1,061 mining and minerals facilities (including mines, plants, mills, or refineries) in Africa, of which less than 5 percent are Chinese owned, or have Chinese interests.[1]

Furthermore, China is a relative latecomer in the mining and minerals industry abroad; Western firms and governments of developing countries themselves have been mining South America, Southeast Asia, and Africa since the 1800s. Higher quality mines are already spoken for, and China is often left (despite the two recent high-profile copper deals described above) investing in mines of marginal quality.[1] Its relative lack of experience has cost it dearly. Approximately 67 percent of Chinese overseas projects fail or go bankrupt.[1] In Katanga Province, DRC, for example, prior to 2008 there were as many as 70 Chinese owned copper/cobalt processing facilities. By 2010, there were thirty, and now there are only four or five.[1] Ultimately, "the scale of [Chinese] investment remains limited compared to that of other major players and will still lag even in ten years, given the strong head-start that others have. China remains a minor participant in minerals…"[1] Nevertheless, China is often the biggest source of new investment and growth in particular countries, and they are adapting their efforts to overcome their late start.[1]

China's enormous stature as a manufacturing country and major consumer of the world's metals has positioned it to dominate the downstream activities related to many commodities. In steelmaking for example, the world's iron ore flows to China because it has over 3000 steel firms. Japan has only five, Korea and Turkey, one each.[1] Magnesium tells a similar story; China has over 300 firms making magnesium metal; the U.S. has one. And again with copper; China has hundreds of smelters; Chile – the world's largest copper producer, has only seven. The U.S. has only three. According to industry experts in Chile, the country's copper producers now ship more raw ore to China for processing than fine copper cathode or even concentrate. Until 2015, Chile had exported more copper cathode than ore. This trend applies not only to base metals, but precious and minor metals as well. China owns over 97 percent of the world's REE oxide and concentrate capability, and 100 percent of the world's REE metal production. Similarly, even though 67 percent of the world's tantalum is mined in Africa, 50 percent of the world's tantalum processing facilities are in China.[1]

For the U.S. to continue enjoying strategic advantage, it will need to assess and learn from Chinese practices as well as and counter them. At a minimum, these conditions strongly suggest four critical elements for our basic strategy: (1) finding ways to encourage continued U.S. foreign direct investment in extraction and beneficiation projects for strategic materials; (2) incentivizing U.S. firms to capture the downstream activities of emerging strategic materials applications that are not already dominated by China (Lithium, for example); (3) what seems overly obvious – maintaining strong bilateral relationships with Australia, Canada, South Africa, Chile, and other existing strong partner nations; and, (4) developing such ties with countries in which strategic materials are prevalent – Brazil, the Democratic Republic of Congo and perhaps a dozen other African nations, Indonesia, and so on.

In conclusion, although the international strategic material industry environment favors China, there are multiple trading partners that can provide many of the materials our defense, energy and technology industry require. It is essential that the U.S. foster strong trading relationships and encourage oversea investments with these reliable trading partners to maintain a competitive global strategic material industry.

Appendix E

Rare Earth Elements on the Periodic Table

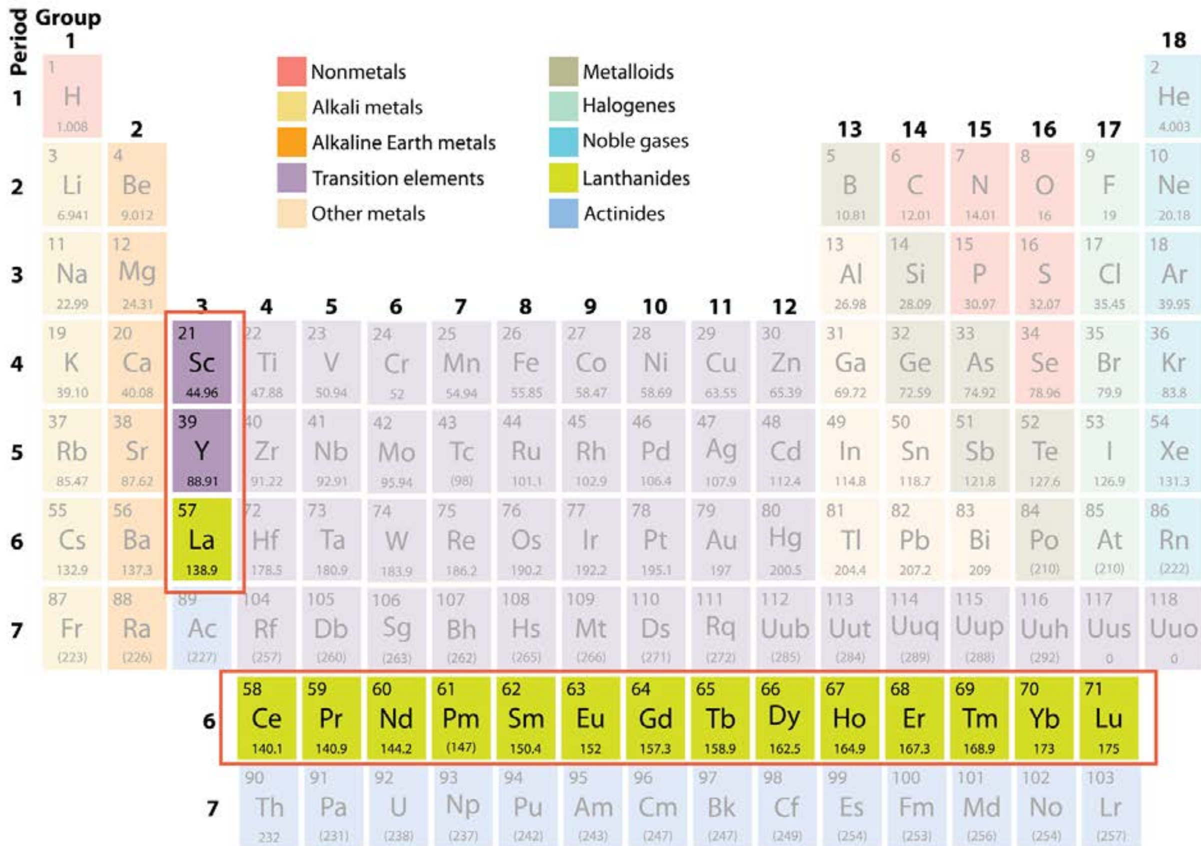
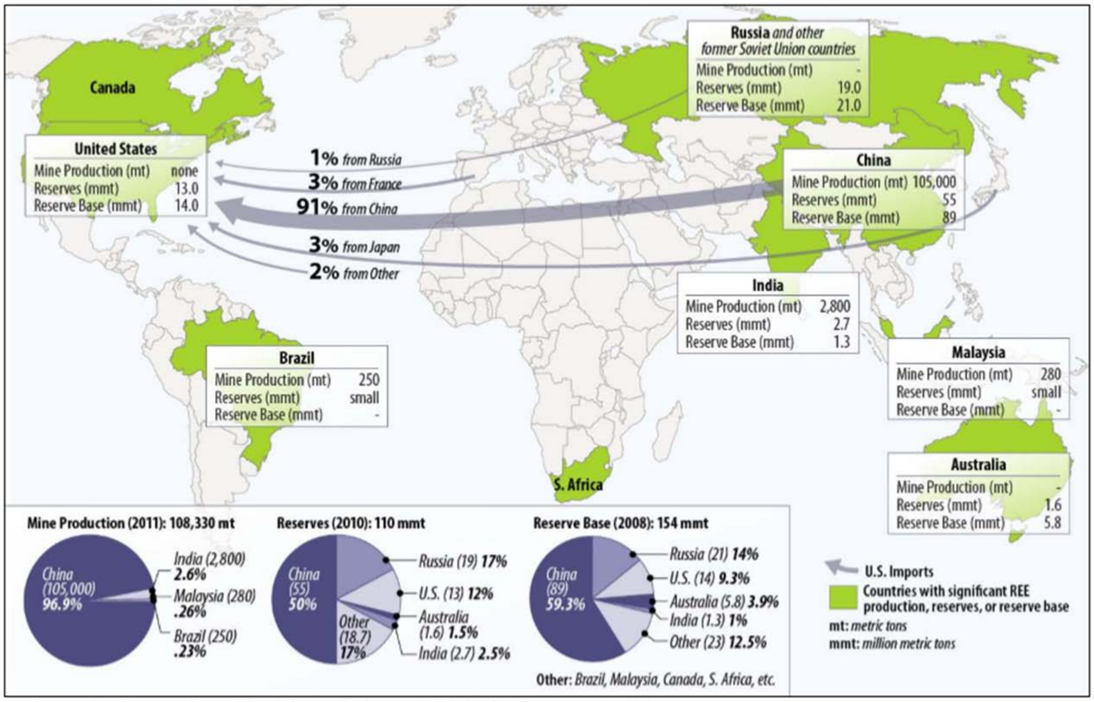


Figure 10: Rare Earth Elements[1]

Appendix F: REE Production, Reserves, U.S. Imports

Figure 4. Rare Earth Elements: World Production, Reserves and U.S. Imports



Source: U.S. Geological Survey, Mineral Commodity Summaries, 2008-2013. (Figure created by CRS.)